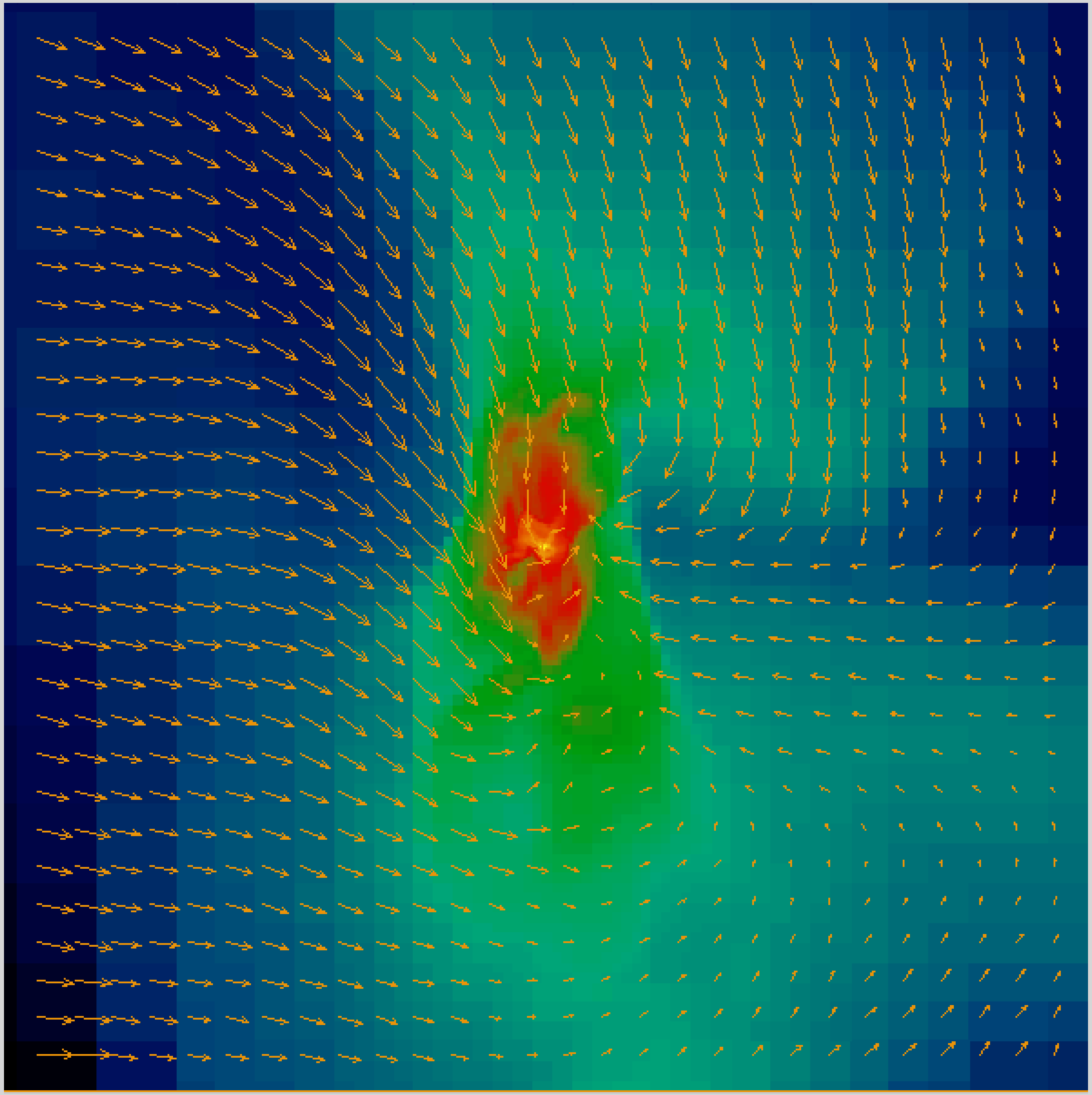
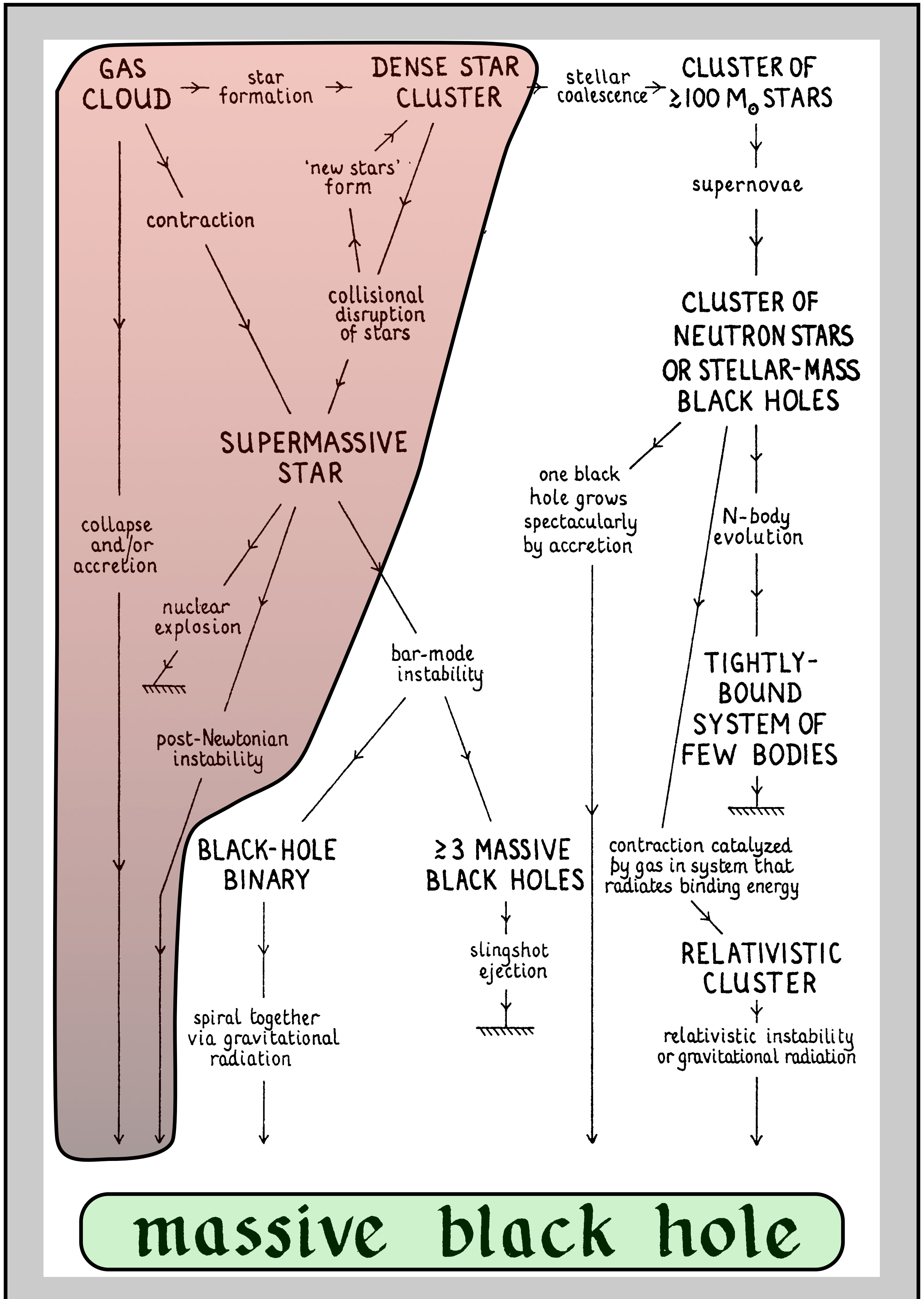


Protogalactic SMBH Formation by Turbulent Collapse

John Wise (KIPAC / Stanford)
Collaborators: Tom Abel, Matt Turk (KIPAC)

Our scope in SMBH formation

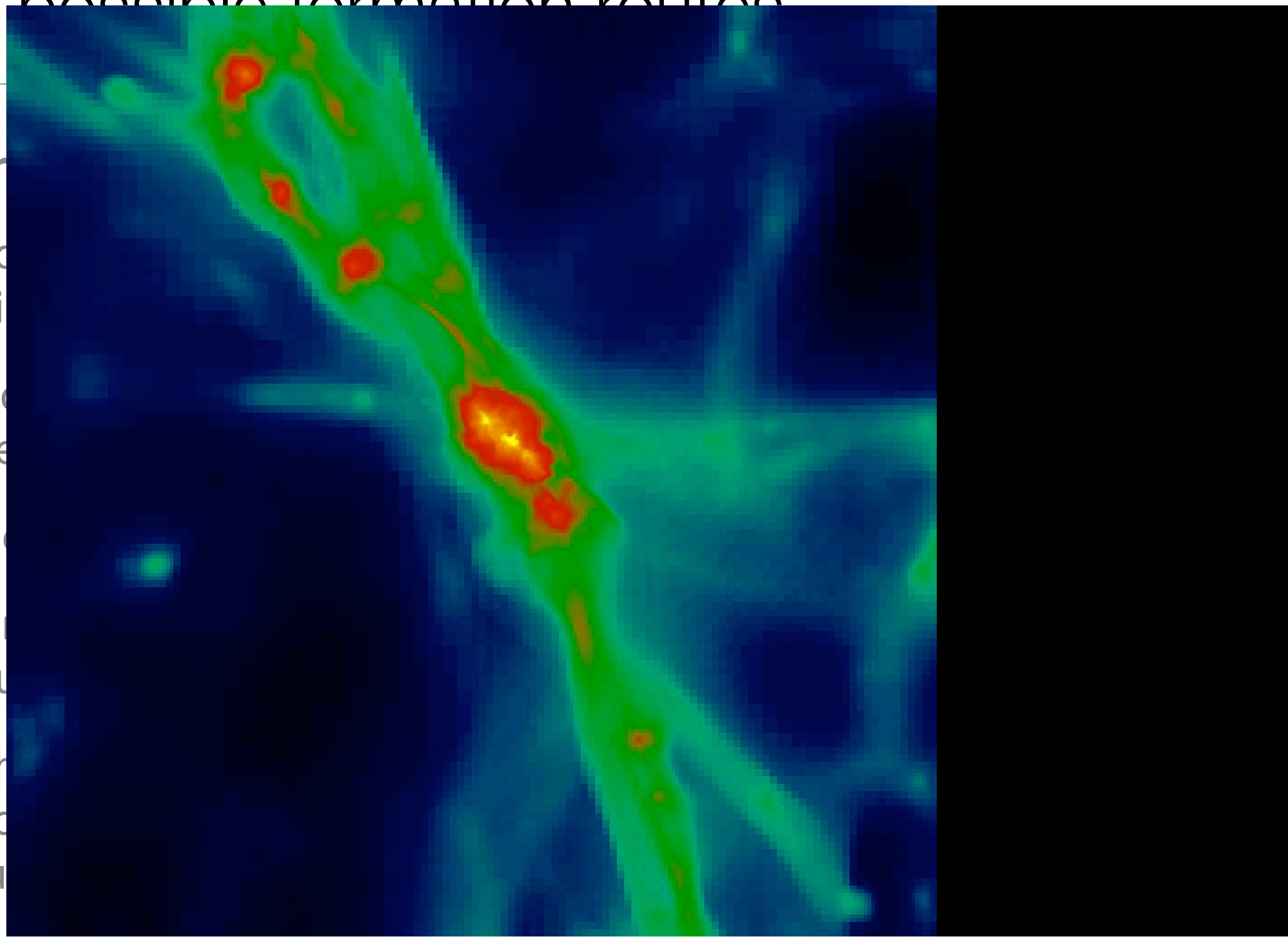


Rees (1984)

Two possible formation routes

- **Accretion**
  - For Pop III stellar masses 40 $M_\odot$< M <100 $M_\odot$ or > 260 $M_\odot$, the star directly collapses into a BH.
  - However, the intense radiation during the main sequence creates an under dense medium of 1 cm^{-3} and most of the gas is expelled from the cloud.
- **Monolithic collapse**
  - Once the gas can cool efficiently (i.e., $t_{cool} < t_{dyn}$), the cloud proceeds to quasistatically collapse.
  - The details of the resulting BH and galaxy depends on the initial configuration of various quantities, such as angular momentum, turbulence, metallicity, etc.

Two possible formation routes



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Two possible formation routes

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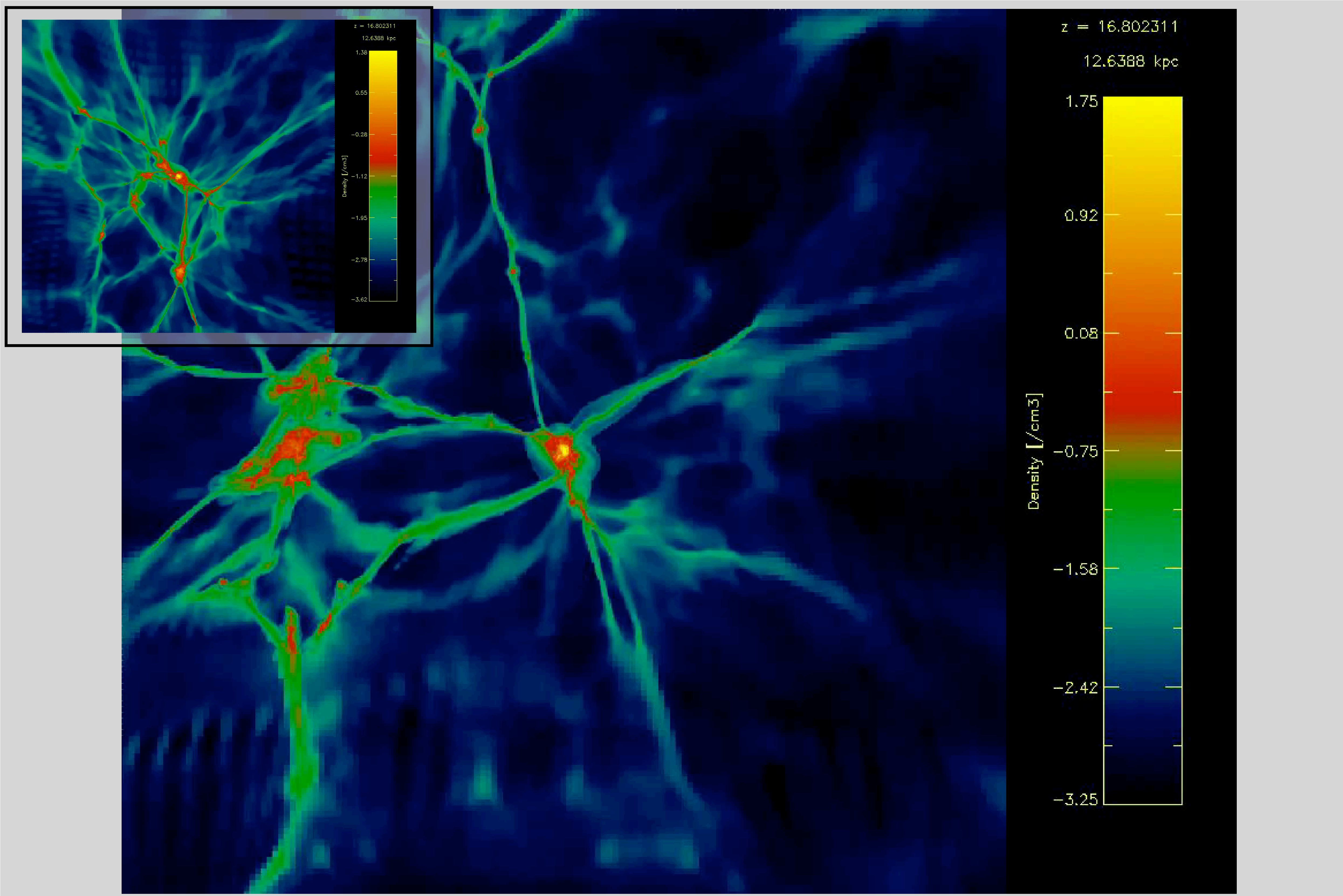
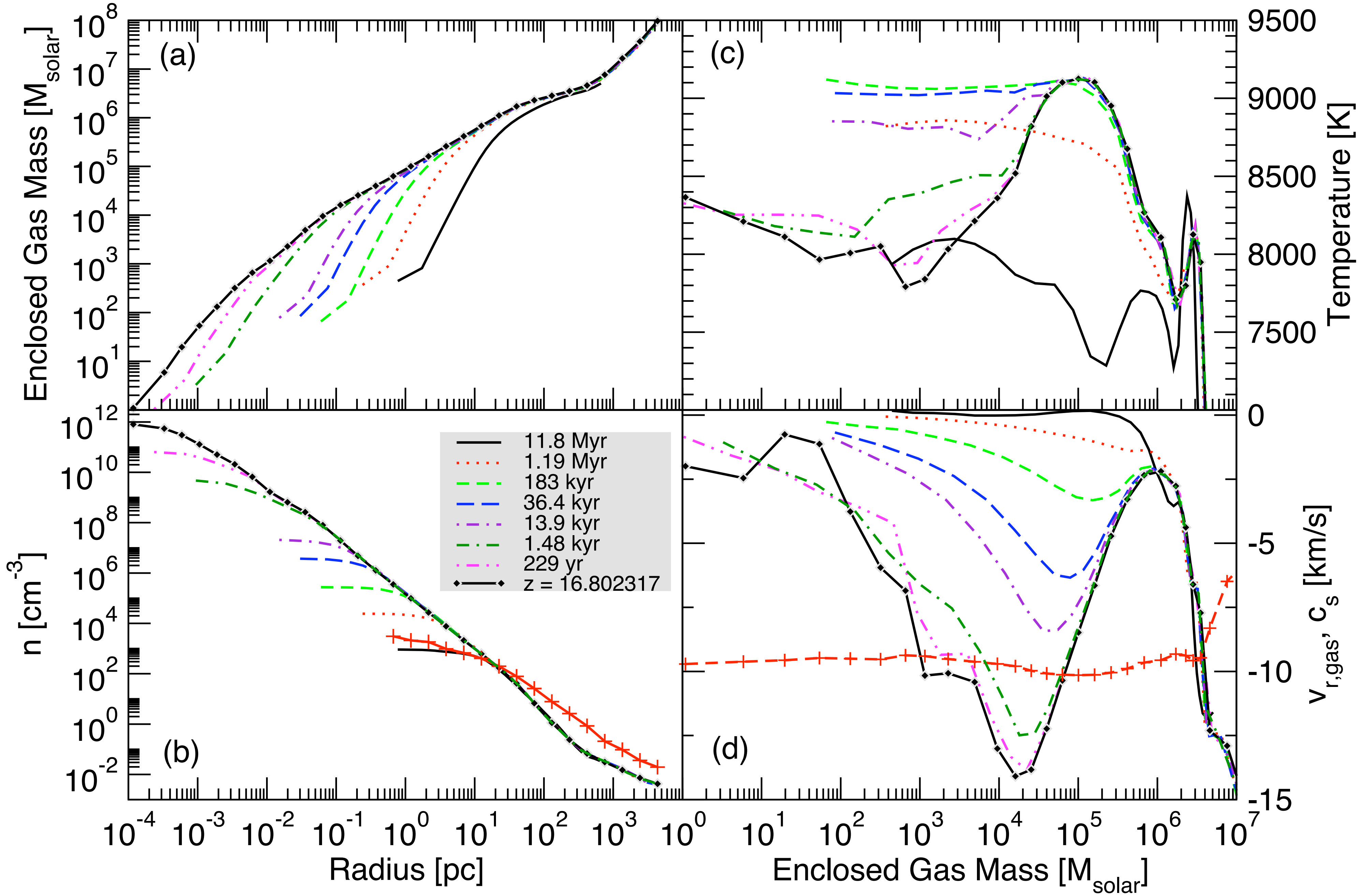
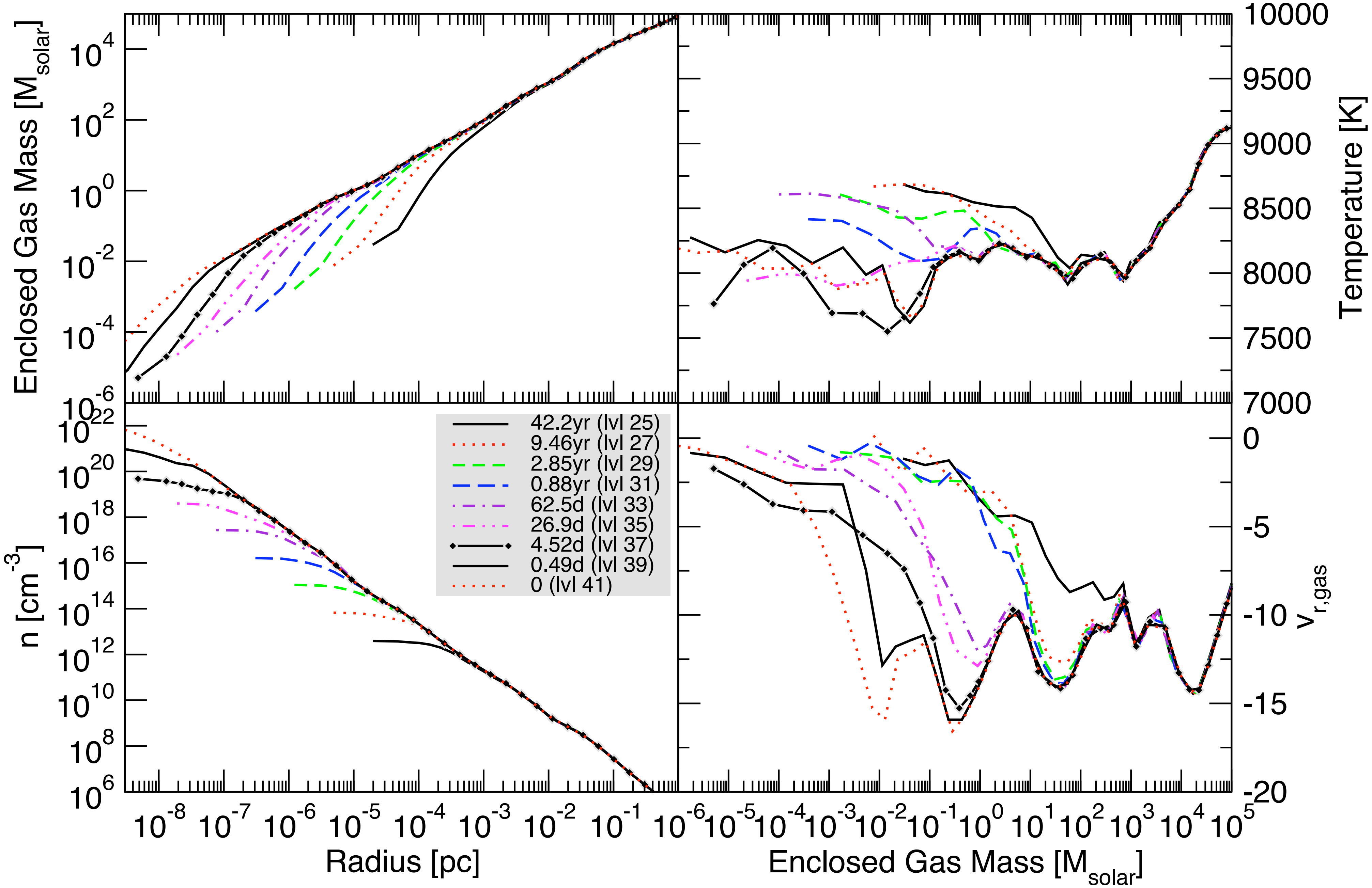


Zoom of 10^{12}. $M_{vir} = 3 \times 10^7\ M_\odot$. $10^5\ M_\odot$ within the center 1pc are gravitationally unstable. We expect a BH to form. No stable large-scale disk (yet).



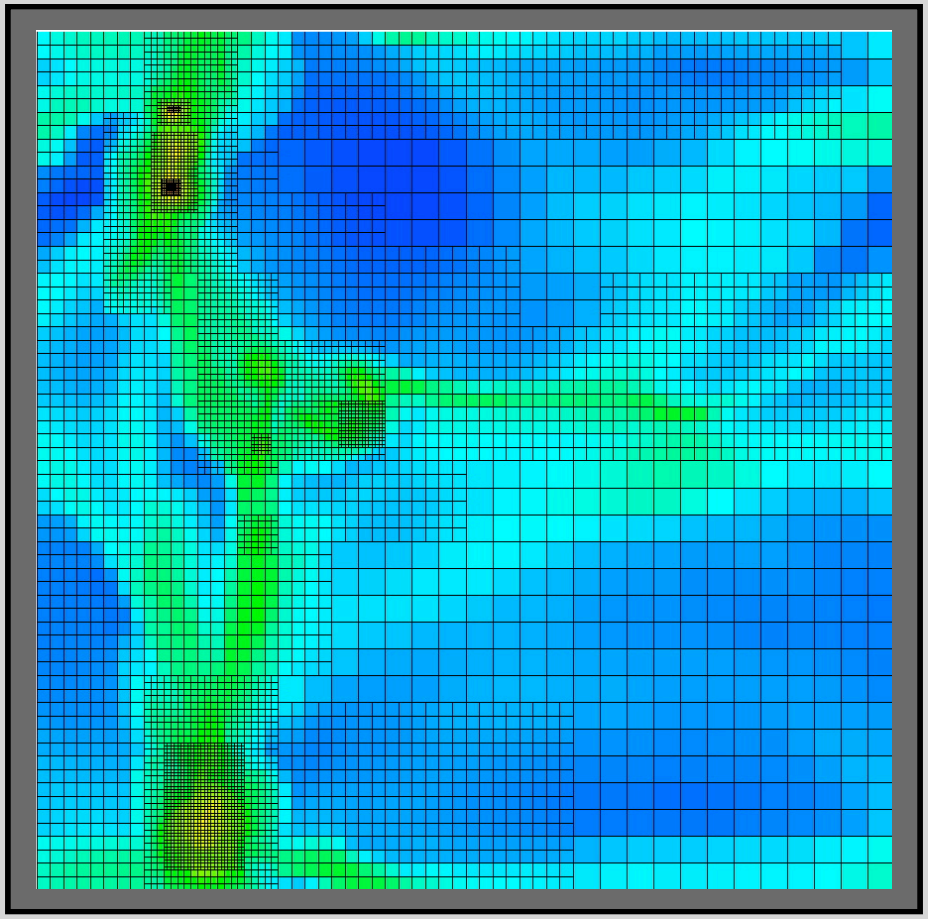
A 10^5 $M_\odot$ collapse depicted by radial profiles.

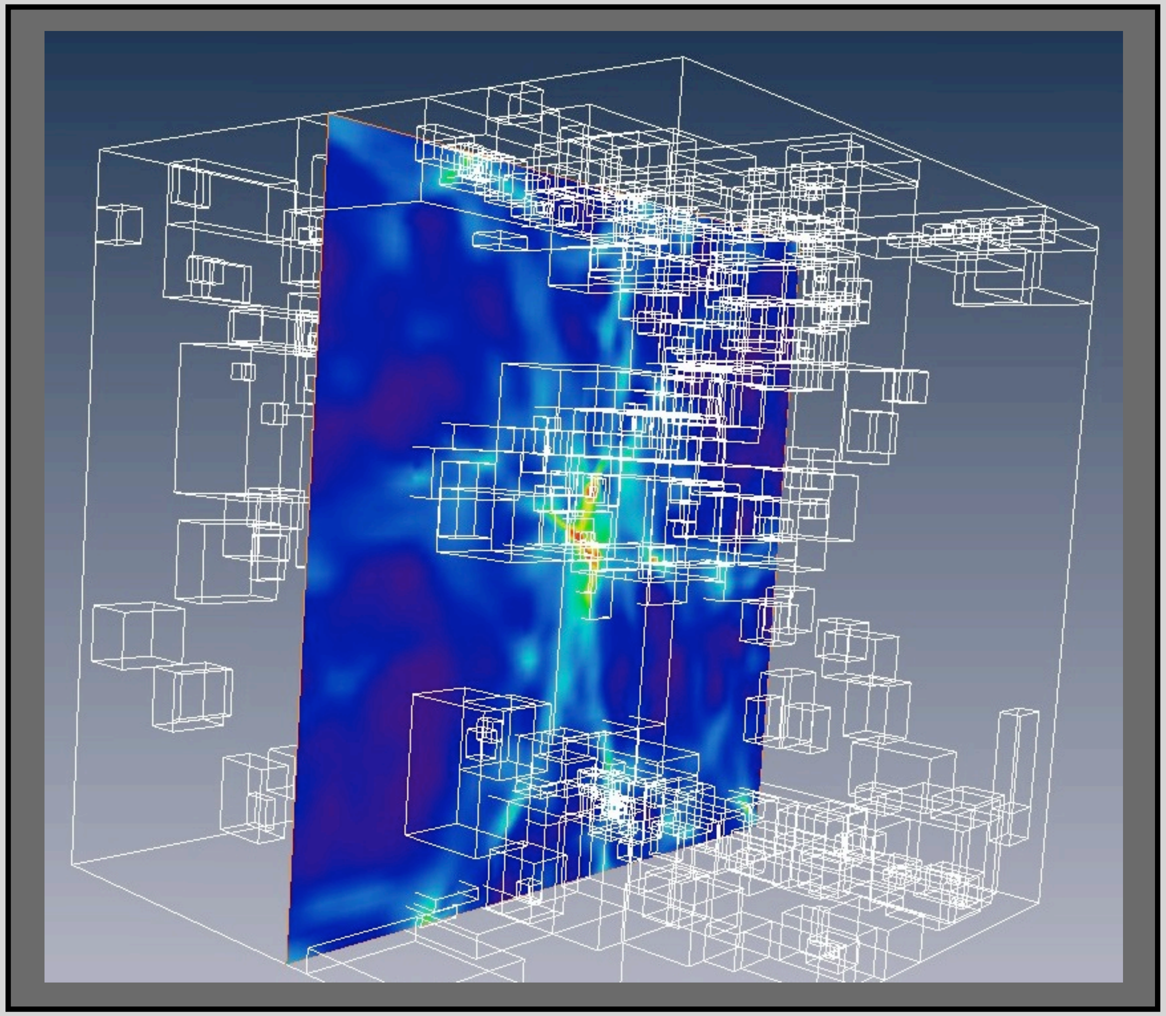


A 10^5 $M_\odot$ collapse depicted by radial profiles.

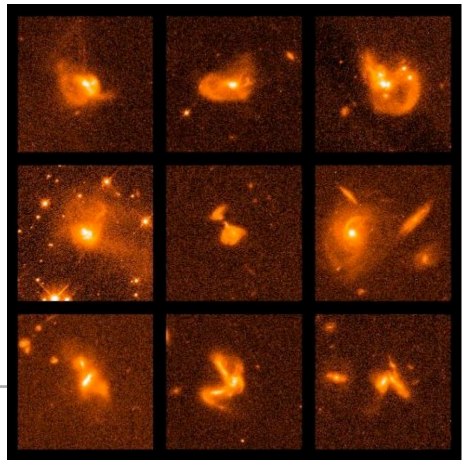
Computational Setup

- **Adaptive Mesh Refinement**
  - 41 levels of refinement based on baryonic and DM density and Jeans length.
  - Resulting in a dynamic range of $10^{14.5}$ in length scales.
  - 22 179 grids
  - 74 000 000 (420^3) unique cells
  - 0.01 $R_\odot$ maximal resolution
  - 1.5 comoving Mpc box





Implications on Galaxy Formation



- We see *no initial* disk formation but a massive (10^5 $M_\odot$) turbulent central object forming.
- The feedback from this central source, whether it be a SMBH or starburst, will have a grand impact on the subsequent large-scale disk.
- There exists enough low angular momentum material to collapse to the inner parsec.
- Then gravitational instabilities transport angular momentum outwards, and supersonic turbulence can dissipate additional energy.
- However in another realization, turbulent heating slows the collapse and might result in a starburst instead.
- The processes seen in our simulations are relevant for theories that postulate SMBH formation from the direct collapse of baryons.

The Pursuit of Completeness

Currently

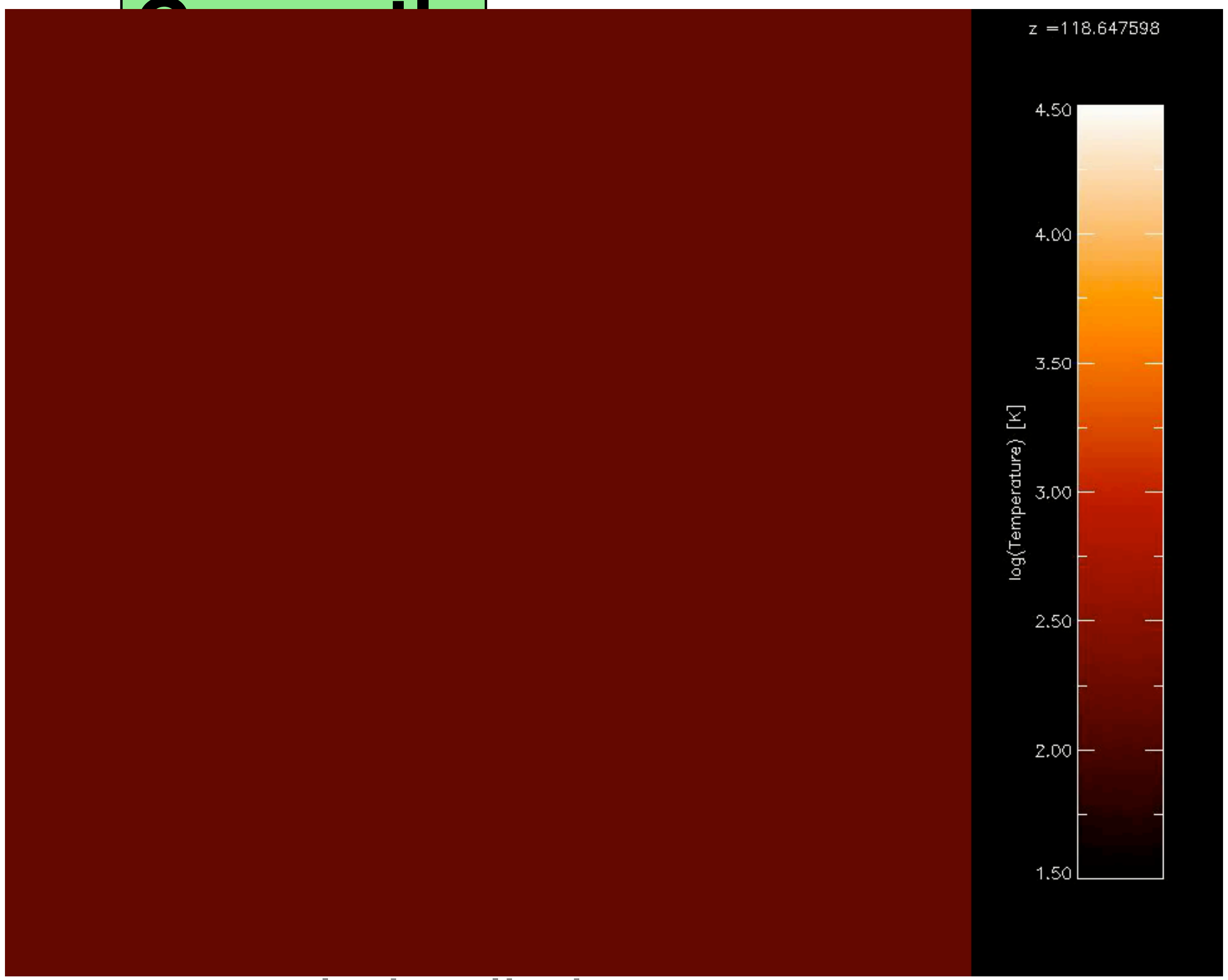
1. Radiative transfer from primordial stars (~20). The first primordial star forms at $z = 31$
2. Tracking of SNe metal ejecta
3. Molecular hydrogen cooling
4. Accreting (sink) particles at the resolution limit

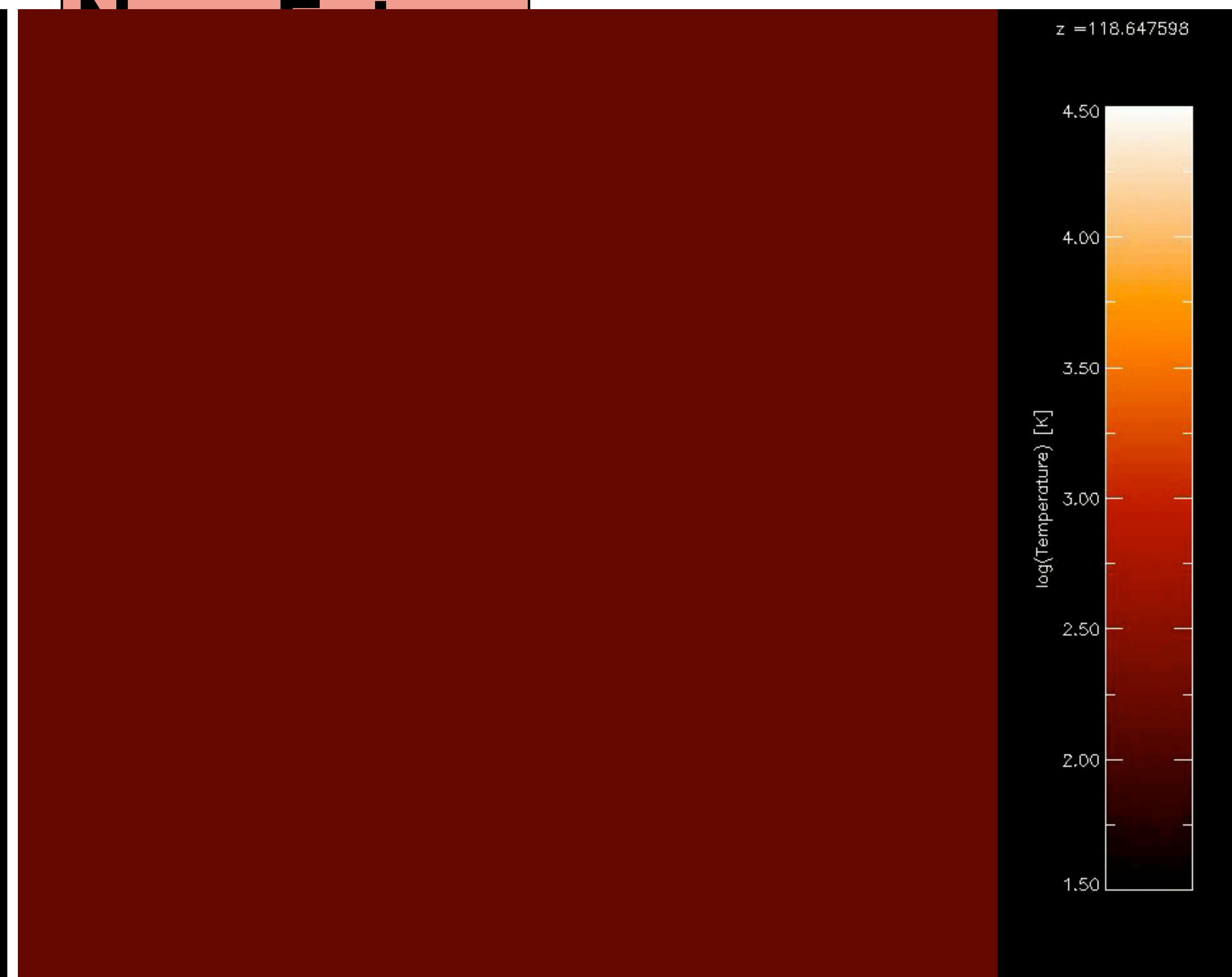
Near Future

1. Radiative accreting particles
2. Population II star formation
3. Seed BH tracking and accretion
4. Magnetic fields (Ideal MHD)

➡ Form a high redshift dwarf galaxy

The Pursuit of Completeness





resolution limit

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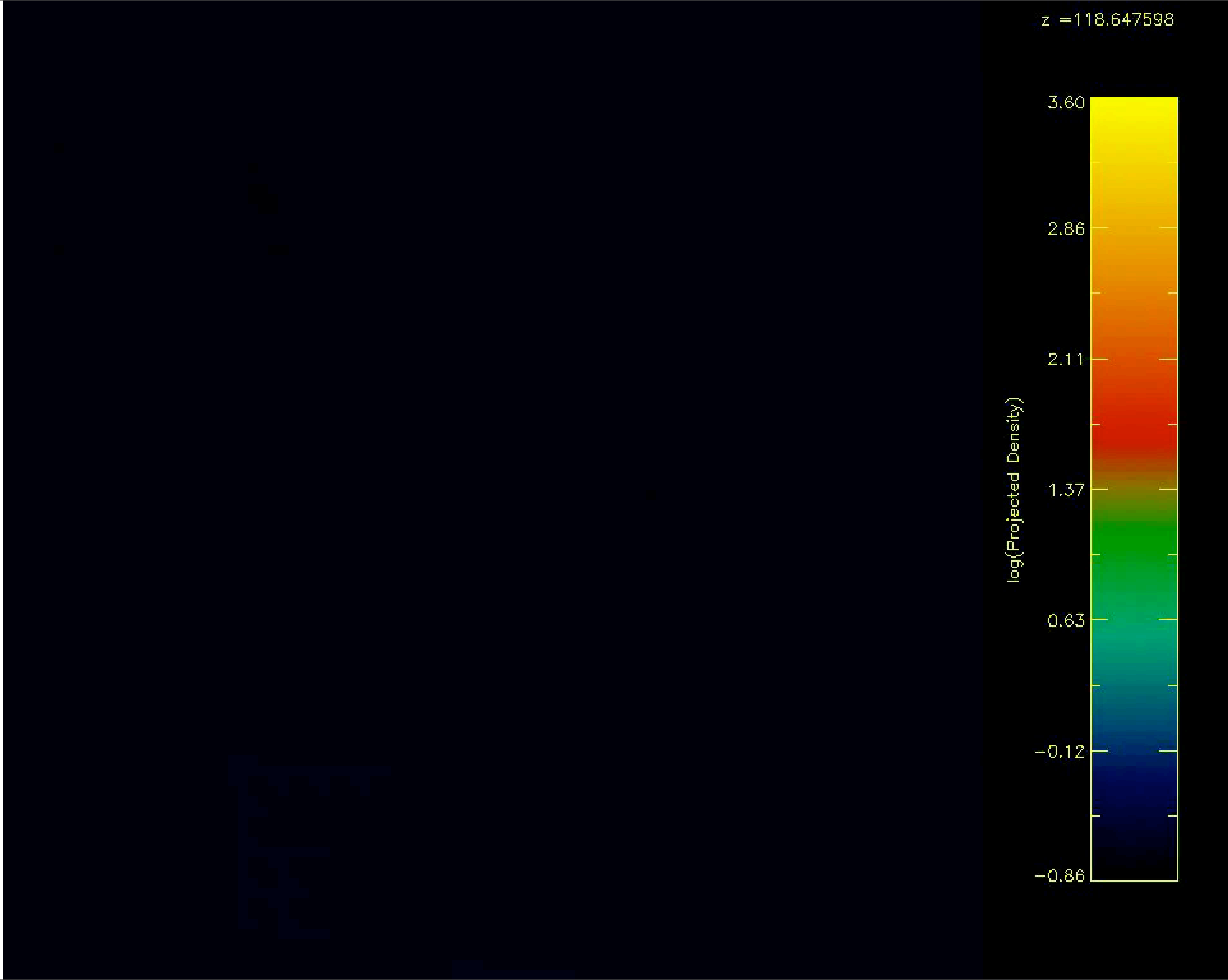
z =118.647598
3.60
2.86
2.11
1.37
0.63
−0.12
−0.86
log(Projected Density)

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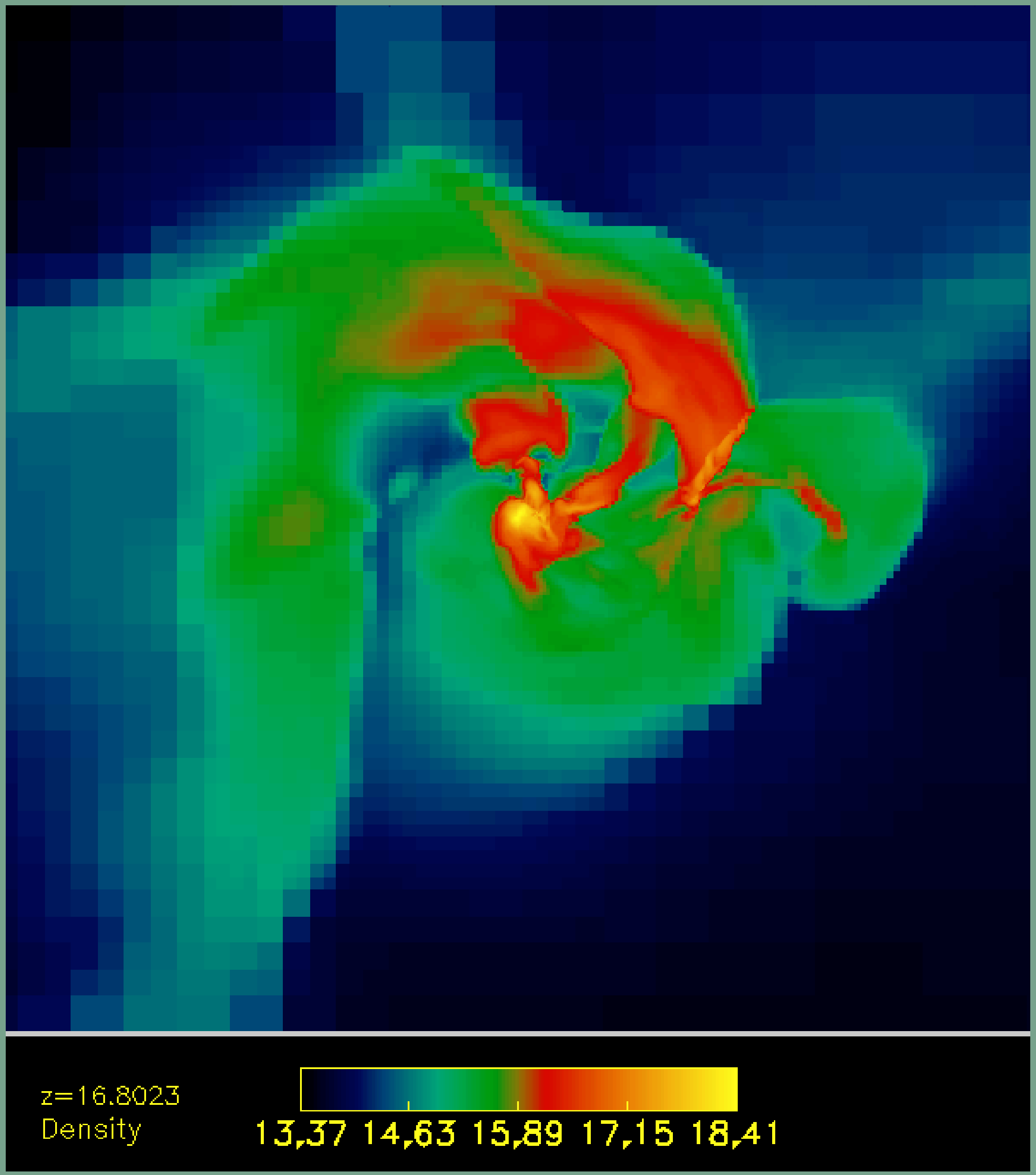

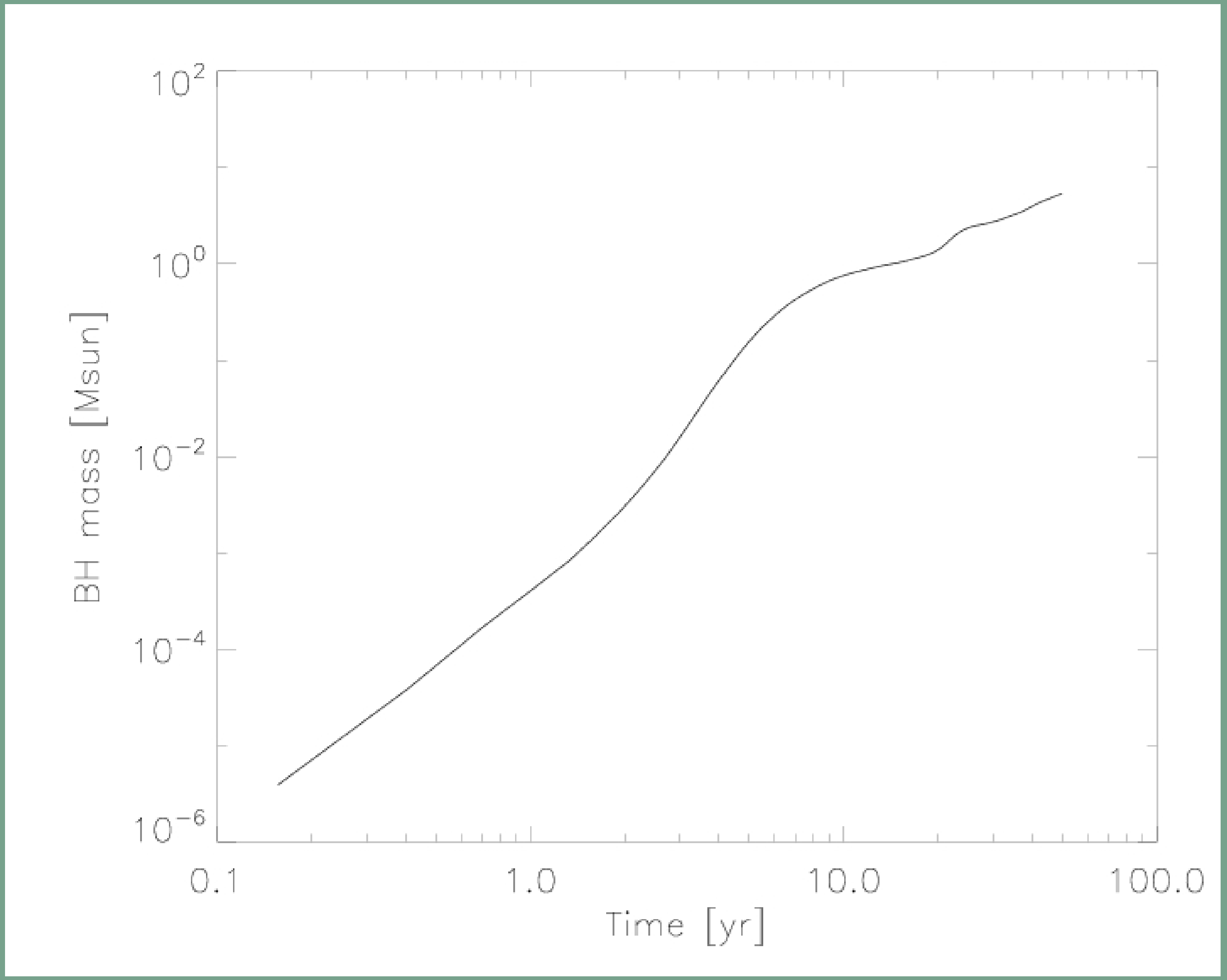

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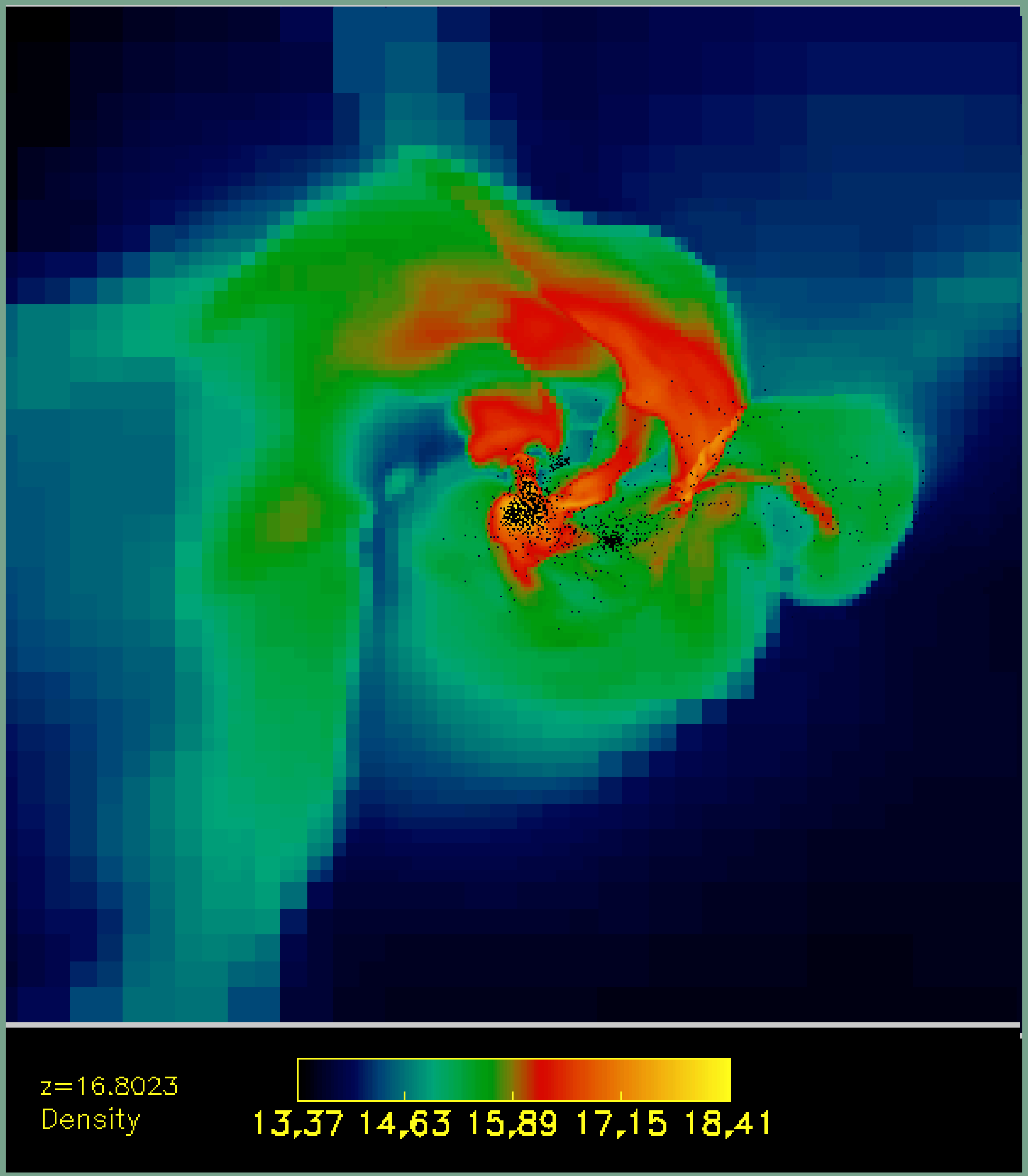

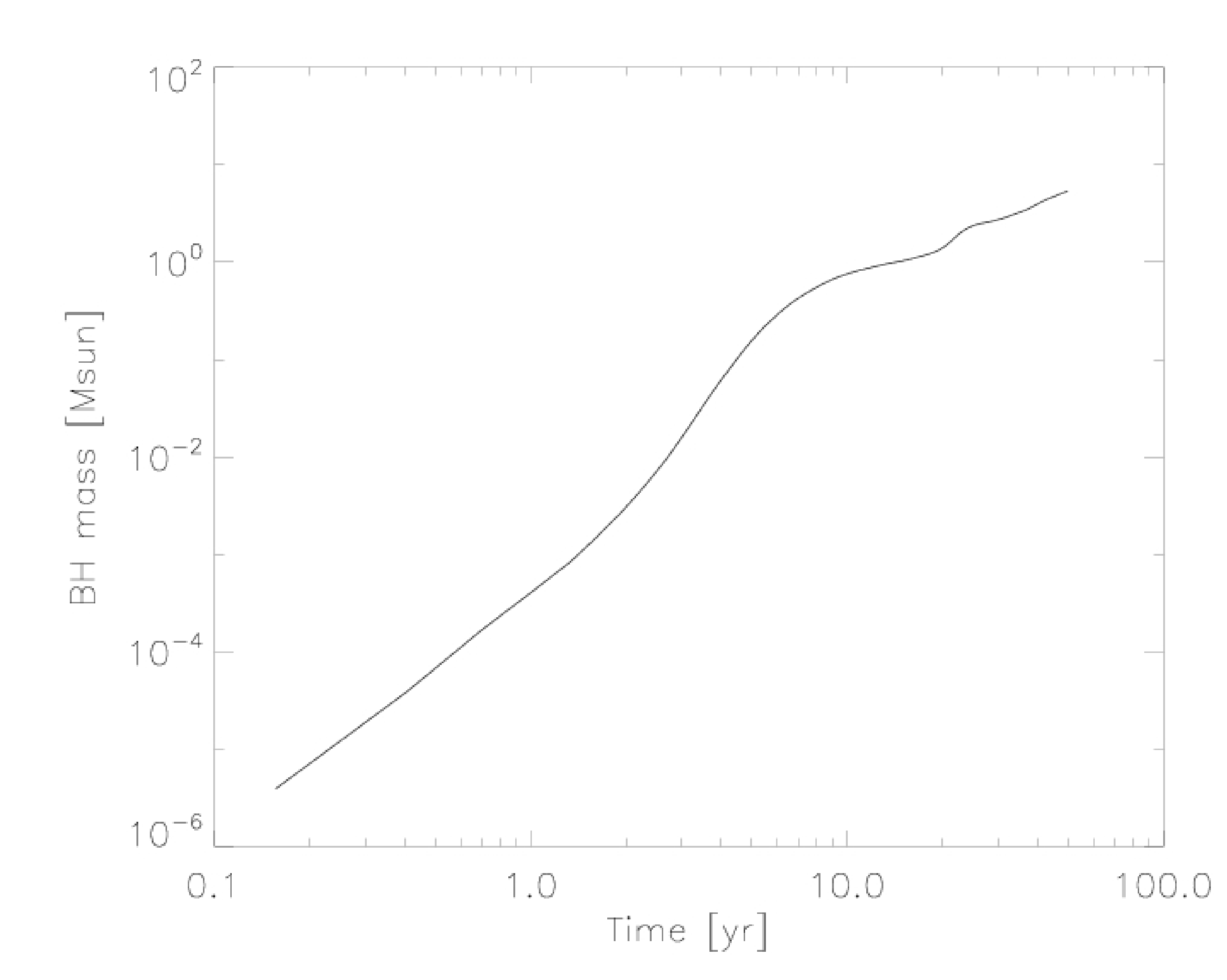

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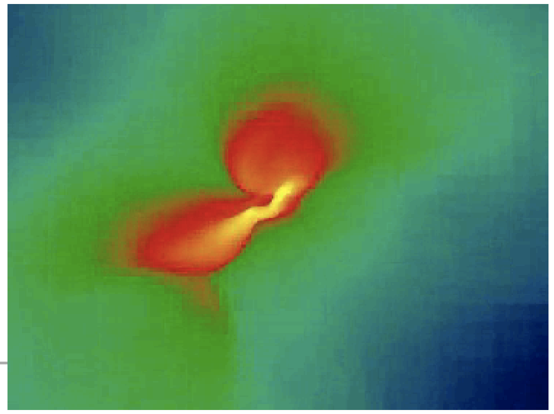
Summary



- We follow the collapse of a turbulent, gravitationally unstable 10^5 $M_\odot$ core in a 3 x 10^7 $M_\odot$ halo at z = 17. In this realization, we expect a SMBH to form.
- *Gravitational instabilities* and *supersonic turbulence* drive the collapse to smaller scales without becoming rotationally supported.
- The amount of *turbulence* may influence the final state (i.e. SMBH or starburst) of the central object.
- The feedback from a central BH will undoubtedly affect subsequent star formation in the “large-scale” (50 pc) disk.
- With only atomic cooling, one finds no fragmentation to multiple objects down to sub-solar scales. Does this ever occur in nature?
- Neglecting H2 and the Pop III progenitors is what allows the BH simulation. Nature may never do this. However, it clearly is a wonderful testbed for the idea of turbulent collapse. It also shows what standard simulations of galaxy formation should find.
- For the next step, we are currently simulating the primordial star formation and its effect on the first galaxies.